



NASA SBIR 2012 Phase I Solicitation

S2 Advanced Telescope Systems

The NASA Science Missions Directorate seeks technology for cost-effective high-performance advanced space telescopes for astrophysics and Earth science. Astrophysics applications require large aperture light-weight highly reflecting mirrors, deployable large structures and innovative metrology, control of unwanted radiation for high-contrast optics, precision formation flying for synthetic aperture telescopes, and cryogenic optics to enable far infrared telescopes. A few of the new astrophysics telescopes and their subsystems will require operation at cryogenic temperatures as cold as 4-degrees Kelvin. This topic will consider technologies necessary to enable future telescopes and observatories collecting electromagnetic bands, ranging from UV to millimeter waves, and also include gravity waves. The subtopics will consider all technologies associated with the collection and combination of observable signals. Earth science requires modest apertures in the 2 to 4 meter size category that are cost effective. New technologies in innovative mirror materials, such as silicon, silicon carbide and nanolaminates, innovative structures, including nanotechnology, and wavefront sensing and control are needed to build telescopes for Earth science.

Subtopics

S2.01 Proximity Glare Suppression for Astronomical Coronagraphy

Lead Center: JPL

Participating Center(s): ARC, GSFC

This subtopic addresses the unique problem of imaging and spectroscopic characterization of faint astrophysical objects that are located within the obscuring glare of much brighter stellar sources. Examples include planetary systems beyond our own, the detailed inner structure of galaxies with very bright nuclei, binary star formation, and stellar evolution. Contrast ratios of one million to ten billion over an angular spatial scale of 0.05-1.5 arcsec are typical of these objects. Achieving a very low background requires control of both scattered and diffracted light. The failure to control either amplitude or phase fluctuations in the optical train severely reduces the effectiveness of starlight cancellation schemes.

This innovative research focuses on advances in coronagraphic instruments, starlight cancellation instruments, and potential occulting technologies that operate at visible and near infrared wavelengths. The ultimate application of these instruments is to operate in space as part of a future observatory mission. Measurement techniques include imaging, photometry, spectroscopy, and polarimetry. There is interest in component development, and innovative instrument design, as well as in the fabrication of subsystem devices to include, but not limited to, the following

areas:

Starlight Suppression Technologies

- Advanced aperture apodization and aperture shaping techniques.
- Advanced apodization mask or occulting spot fabrication technology controlling smooth density gradients to 10⁻⁴ with spatial resolutions ~1 μm, low dispersion, and low dependence of phase on optical density, in linear and circular patterns.
- Metrology for detailed evaluation of compact, deep density apodizing masks, Lyot stops, and other types of graded and binary mask elements. Development of a system to measure spatial optical density, phase inhomogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of masks and stops is needed.
- Interferometric starlight cancellation instruments and techniques to include aperture synthesis and single input beam combination strategies.
- Pupil remapping technologies to achieve beam apodization.
- Techniques to characterize highly aspheric optics.
- Methods to distinguish the coherent and incoherent scatter in a broad band speckle field.
- Methods of polarization control and polarization apodization.
- Components and methods to insure amplitude uniformity in both coronagraphs and interferometers, specifically materials, processes, and metrology to insure coating uniformity.
- Coherent fiber bundles consisting of up to 10⁴ fibers with lenslets on both input and output side, such that both spatial and temporal coherence is maintained across the fiber bundle for possible wavefront/amplitude control through the fiber bundle.

Wavefront Control Technologies

- Development of small stroke, high precision, deformable mirrors and associated driving electronics scalable to 104 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple deformable mirror technologies in various phases of development and processes are encouraged to ultimately improve the state-of-the-art in deformable mirror technology. Process improvements are needed to improve repeatability, yield, and performance precision of current devices.
- Development of instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront.
- Adaptive optics actuators, integrated mirror/actuator programmable deformable mirror.
- Reliability and qualification of actuators and structures in deformable mirrors to eliminate or mitigate single actuator failures.
- Multiplexer development for electrical connection to deformable mirrors that has ultra-low power dissipation.

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- High precision wavefront error sensing and control techniques to improve and advance coronagraphic imaging performance.
 - Development of techniques to improve the wavefront stability of the telescope beam, and/or to mitigate the residual instability. These include but are not limited to: the development of low order wavefront sensors, improved pointing techniques, as well as model-based software algorithms that predict and subtract the instabilities in post-processing.

Optical Coating and Measurement Technologies

- Instruments capable of measuring polarization cross-talk and birefringence to parts per million.
- Highly reflecting broadband coatings for large (> 1 m diameter) optics.
- Polarization-insensitive coatings for large optics.

Other

- Artificial star and planet, point sources, with $1e10$ dynamic range and uniform illumination of an f/25 optical system, working in the visible and near infrared.
- Deformable, calibrated, collimating source to simulate the telescope front end of a coronagraphic system undergoing thermal deformations.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

S2.02 Precision Deployable Optical Structures and Metrology

Lead Center: JPL

Participating Center(s): GSFC, LaRC

Planned future NASA Missions in astrophysics, such as the Wide-Field Infrared Survey Telescope (WFIRST) and the New Worlds Technology Development Program (coronagraph, external occulter and interferometer technologies) will push the state of the art in current optomechanical technologies. Mission concepts for New Worlds science would require 10 - 30 m class, cost-effective telescope observatories that are diffraction limited at wavelengths from the visible to the far IR, and operate at temperatures from 4 - 300 K. In addition, ground based telescopes such as the Cerro Chajnantor Atacama Telescope (CCAT) requires similar technology development.

The desired areal density is $1 - 10 \text{ kg/m}^2$ with a packaging efficiency of 3-10 deployed/stowed diameter. Static and dynamic wavefront error tolerances to thermal and dynamic perturbations may be achieved through passive means

(e.g., via a high stiffness system, passive thermal control, jitter isolation or damping) or through active opto-mechanical control. Large deployable multi-layer structures in support of sunshades for passive thermal control and 20m to 50m class planet finding external occulters are also relevant technologies. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be the Earth-Sun L2.

This subtopic solicits proposals to develop enabling, cost effective component and subsystem technology for deploying large aperture telescopes with low cost. Research areas of interest include:

- Precision deployable structures and metrology for optical telescopes (e.g., innovative active or passive deployable primary or secondary support structures).
- Architectures, packaging and deployment designs for large sunshields and external occulters.

In particular, important subsystem considerations may include:

- Innovative concepts for packaging fully integrated subsystems (e.g., power distribution, sensing, and control components).
- Mechanical, inflatable, or other precision deployable technologies.
- Thermally-stable materials (CTE
- Innovative systems, which minimize complexity, mass, power and cost.
- Innovative testing and verification methodologies.

The goal for this effort is to mature technologies that can be used to fabricate 16 m class or greater, lightweight, ambient or cryogenic flight-qualified observatory systems. Proposals to fabricate demonstration components and subsystems with direct scalability to flight systems through validated models will be given preference. The target launch volume and expected disturbances, along with the estimate of system performance, should be included in the discussion. Proposals with system solutions for large sunshields and external occulters will also be accepted. A successful proposal shows a path toward a Phase II delivery of demonstration hardware scalable to 5 meter diameter for ground test characterization.

Before embarking on the design and fabrication of complex space-based deployable telescopes, additional risk reduction in operating an actively controlled telescope in orbit is desired. To be cost effective, deployable apertures that conform to a cubesat (up to 3-U) or ESPA format are desired. Consequently, deployment hinge and latching concepts, buildable for these missions and scaleable to larger systems are desired. Such a system should allow

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop the relevant subsystem technologies and to transition into future NASA program(s).

S2.03 Advanced Optical Component Systems

Lead Center: MSFC

Participating Center(s): GSFC, JPL

This subtopic solicits solutions in the following areas:

- Optical Components, Coatings and Systems for potential X-ray missions.
- Optical Components, Coatings and Systems for potential UV/Optical missions.
- Large aperture diffusers (up to 1 meter) to calibrate GeoStationary Earth viewing sensors.

The 2010 National Academy Astro2010 Decadal Report specifically identifies optical components and coatings as key technologies needed to enable several different future missions, including:

- Light-weight X-ray imaging mirrors for future large advanced X-ray observatories.
- Large aperture, light-weight mirrors for future UV/Optical telescopes.
- Broadband high reflectance coatings for future UV/Optical telescopes.

The 2012 National Academy report "NASA Space Technology Roadmaps and Priorities" states that one of the top technical challenges in which NASA should invest over the next five years is developing a new generation of larger effective aperture, lower-cost astronomical telescopes that enable discovery of habitable planets, facilitate advances in solar physics, and enable the study of faint structures around bright objects. To enable this capability requires low-cost, ultra-stable, large-aperture, normal and grazing incidence mirrors with low mass-to-collecting area ratios. To enable these new astronomical telescopes, the report identifies three specific optical systems technologies:

- Active align/control of grazing-incidence imaging systems to achieve
- Active align/control of normal-incidence imaging systems to achieve 500 nm diffraction limit (40 nm rms wavefront error, WFE) performance.
- Normal incidence 4-meter (or larger) diameter 5 nm rms WFE (300 nm system diffraction limit) mirrors.

Finally, effecting potential space telescopes, NASA is developing a heavy lift space launch system (SLS). An SLS with an 8 to 10 meter fairing and 80 to 100 mt capacity to LEO would enable extremely large space telescopes. Potential systems include 12 to 30 meter class segmented primary mirrors for UV/optical or infrared wavelengths and 8 to 16 meter class segmented X-ray telescope mirrors. These potential future space telescopes have very specific mirror technology needs. UV/optical telescopes (such as ATLAST-9 or ATLAST-16) require 1 to 3 meter class mirrors with

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

Technical Challenges

In all cases, the most important metric for an advanced optical system is affordability or areal cost (cost per square meter of collecting aperture). Currently both X-ray and normal incidence space mirrors cost \$4 million to \$6 million per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 5 to 50 times, to less than \$1M to \$100K/m².

Successful proposals shall provide a scale-up roadmap (including processing and infrastructure issues) for full scale space qualifiable flight optics systems. Material behavior, process control, active and/or passive optical performance, and mounting/deploying issues should be resolved and demonstrated.

Optical Components, Coatings and Systems for potential X-ray missions

Potential X-ray missions require:

- X-ray imaging telescopes with 1 to 5 m² collecting area.
- Multilayer high-reflectance coatings for hard X-ray mirrors (similar to NuSTAR).
- X-ray transmission and/or reflection gratings.

Multiple technologies are needed to enable

For example, the Wide-Field X-Ray Telescope (WFXT) requires a 6 meter focal length X-ray mirror with 1 arc-sec resolution and 1 m² of collecting area. One implementation of this mirror has 71 concentric full shell hyperbola/parabola pairs whose diameters range from 0.3 to 1.0 meter and whose length is 150 to 240 mm (this length is split between the H/P pair). Total mass for the integrated mirror system (shells and structure) is

Successful proposals will demonstrate an ability to manufacture, test and control a prototype X-ray mirror assembly in the 0.25 to 0.5 meter class; or to coat a 0.25 to 0.5 meter class representative optical component. An ideal Phase I deliverable would deliver a sub-scale component such as a 0.25 meter X-ray precision mirror. An ideal Phase II project would further advance the technology to produce a space-qualifiable 0.5 meter mirror, with a TRL in the 4 to 5 range. Both deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. The Phase II would also include a mechanical and thermal stability analysis.

Optical Components, Coatings and Systems for potential UV/Optical missions

Potential UV/Optical missions require:

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- Large aperture, light-weight mirrors.
 - Broadband high reflectance coatings.

Future UVOIR missions require 4 to 8 or 16 meter monolithic or segmented primary mirrors with 2 for a 5 m fairing EELV vs. 60 kg/m² for a 10 m fairing SLS). Additionally, future UVOIR missions require high-reflectance mirror coatings with spectral coverage from 100 to 2500 nm and extremely uniform amplitude and polarization properties.

Successful proposals will demonstrate an ability to manufacture, test and control ultra-low-cost precision 0.25 to 0.5 meter optical systems; or to coat a 0.25 to 0.5 meter representative optical component. Potential solutions include, but are not limited to, new mirror materials such as silicon carbide, nanolaminates or carbon-fiber reinforced polymer; new fabrication processes such as direct precision machining, rapid optical fabrication, roller embossing at optical tolerances, slumping or replication technologies to manufacture 1 to 2 meter (or larger) precision quality mirrors or lens segments. Solutions include reflective, transmissive, diffractive or high order diffractive blazed lens optical components for assembly of large (16 to 32 meter) optical quality primary elements.

Potential solutions to improve UV reflective coatings include, but are not limited to, investigations of new coating materials with promising UV performance; new deposition processes; and examination of handling processes, contamination control, and safety procedures related to depositing coatings, storing coated optics, and integrating coated optics into flight hardware. An ability to demonstrate optical performance on 2 to 3 meter class optical surfaces is important.

An ideal Phase I deliverable would be a precision mirror of at least 0.25 meters; or a coated mirror of at least 0.25 meters. An ideal Phase II project would further advance the technology to produce a space-qualifiable mirror greater than 0.5 meters, with a TRL in the 4 to 5 range. Both deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. The Phase II would also include a mechanical and thermal stability analysis.

Large aperture diffusers (up to 1 meter) to calibrate GeoStationary Earth viewing sensors

The geosynchronous orbit for GEO-CAPE coastal ecosystem imager requires technology for alternative periodic solar calibration strategies including new materials to reduce weight, and new optical analysis to reduce the size of calibration systems. GEO-CAPE will need a light-weight large aperture (greater than 0.5 m) diffuse solar calibrator, employing multiple diffusers to track on-orbit degradation. Typical materials of interest are PTFE (such as Spectralon® surface diffuser) or development of new Mie scattering materials for use as volume diffusers in transmission or reflection. Material needs to be stable in BTDF/BSDF to 2%/year from 250 to 2500 nm and highly lambertian (no formal specification for deviation from lambertian).

Lead Center: GSFC

Participating Center(s): JPL, MSFC

This subtopic focuses primarily on manufacturing and metrology of optical surfaces, especially for very small or very large and/or thin optics. Missions of interest include:

- WFIRST concepts (<http://wfirst.gsfc.nasa.gov/>).
- NGXO (<http://ixo.gsfc.nasa.gov/>).
- SGO (<http://lisa.gsfc.nasa.gov/>).
- ATLAST (<http://www.stsci.edu/institute/atlast/>).

Optical systems currently being researched for these missions are large area aspheres, requiring accurate figuring and polishing across six orders of magnitude in period. Technologies are sought that will enhance the figure quality of optics in any range as long as the process does not introduce artifacts in other ranges. For example, mm-period polishing should not introduce waviness errors at the 20 mm or 0.05 mm periods in the power spectral density. Also, novel metrological solutions that can measure figure errors over a large fraction of the PSD range are sought, especially techniques and instrumentation that can perform measurements while the optic is mounted to the figuring/polishing machine. Large lightweight monolithic metallic aspheres manufactured using innovative mirror substrate materials that can be assembled and welded together from smaller segments are sought. Also, optical system design and tolerancing requires software analysis tools capable of accurately ray tracing a broader range of materials and effects than are currently treated with conventional optical software. Updated software algorithms code is a technology of interest.

By the end of a Phase II program, technologies must be developed to the point where the technique or instrument can dovetail into an existing optics manufacturing facility producing optics at the R&D stage. Metrology instruments should have 10 nm or better surface height resolution and span at least 3 orders of magnitude in lateral spatial frequency.

Examples of technologies and instruments of interest include:

- Innovative metal mirror substrate materials or manufacturing methods such as welding component segments into one monolith that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods.
- Interferometric nulling optics for very shallow conical optics used in X-ray telescopes.
- Segmented systems commonly span 60 ° in azimuth and 200 mm axial length and cone angles vary from 0.1 to 1 °.
- Low stress metrology mounts that can hold very thin optics without introducing mounting distortion.
- Low normal force figuring/polishing systems operating in the 1 mm to 50 mm period range with minimal impact at significantly smaller and larger period ranges.
- In-situ metrology systems that can measure optics and provide feedback to figuring/polishing instruments without removing the part from the spindle.

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- Innovative mirror substrate materials or manufacturing methods that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods.
 - Extreme aspheric and/or anamorphic optics for pupil intensity amplitude apodization.
 - Metrology systems useful for measuring large optics with high precision.
 - Innovative method of bonding extremely lightweight (less than 1 kg/m² areal density) and thin (less than 1 mm) mirrors to a housing structure, preserving both alignment and figure.
 - Innovative method of improving the figure of extremely lightweight and thin mirrors without polishing, such as using the coating stress.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.